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Partial trend identification by change-point successive average methodology (SAM)

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ABSTRACT

There are different trend identification methodologies in the literature, but almost all are for monotonic trend searches within a given hydro-meteorological time series partially at equal epochs or holistically over the whole record duration. The most important question is how to identify within the same time series successive trends of different durations and slopes. For this purpose, successive arithmetic average methodology (SAM) is proposed in this paper, first for a set of trends visual inspection and then their quantitative duration and slope calculations. This method provides to identify peak and valley change-points years, trends durations and slopes. The most significant benefit from SAM is that there is no need for preliminary assumptions and trends identifications are straight forward. The only limitation of the method is short length time series. Absolute relative percentage error control is suggested as ±10% for separation of successive partial trend differences. The application of SAM methodology is presented for more than seventy-year duration total annual rainfall records from seven geographic and climate regions in Turkey. It has been calculated that both increasing and decreasing trend durations have at the maximum 4.5-year duration. According to the calculations, except at one meteorology station almost all the trend slopes are negative, which may be an initial signal for climate change impact indicating the rainfall decreases in recent years over Turkey.

1. Introduction

The literature is full of papers that mention about the significance of trend component analysis in hydro-meteorological time series and such researches gained unprecedented frequency due to the significance of climate change impact on water resources, environment, health and ecosystems (IPCC, 2001, 2007; Chen et al., 2006; Kundzewicz et al., 2007). Apart from the classical probabilistic, statistical and stochastic modeling alternatives, trend identification methodologies provide a room for climate change effect identification and interpretation.

In the literature, trend identification methodologies advanced along two groups, namely, parametric and non-parametric methods. It is known that the parametric methods have more powerful results than non-parametric alternatives, but they have restrictive assumptions as serial independence and normal probability distribution function (PDF) requirements. These methods cannot take into consideration outliers, whereas the non-parametric approaches help on this point even with non-normal PDFs. The first trend detection test in time series analysis is due to Mann (1945) and Kendall (1975), in short as Mann-Kendall (MK) test. This method is supported by Sen (1968) slope calculation procedure. Various researchers have applied this methodology for trend identification with its pros and cons (Hirsch et al., 1982; Hamed and Rao, 1998; van Belle and Hughes, 1984; Zetterqvist, 1991; Zhang et al., 2001, 2004; Burn and Elnur, 2002; Yue et al., 2002; Adamowski and Bougadis, 2003; Yue and Wang, 2004; Yue and Pilon, 2004; Arora et al., 2005; Aziz and Burn, 2006; Gemmer et al., 2004; Kundzewicz and Robson, 2004; Önöz and Bayazit, 2011; Farshad et al., 2015).

On the other hand, recently Şen (2012, 2014, 2017a,b) proposed a simple and effective method for trend detection by means of the innovative trend analysis (ITA) approach, which has attracted many researchers and they applied it to various hydro-meteorological records (Sonali and Kumar, 2013; Elousssi, et al., 2016; Wu and Qian, 2017; Dabanlı et al., 2016; Almazroui et al., 2017, 2018; Şen et al., 2017; Tabari et al., 2017; Mohorji et al., 2017; Güçlü, 2018a,b; Güçlü et al., 2018; Alashan, 2018; Cui et al., 2017; Zarei and Eslamian, 2017; Ahmad et al., 2018; Yan et al., 2018). Güçlü et al. (2018a) used the ITA for rainfall trend qualifications based on the frequency–intensity–duration curves and he compared different interrelated data sets on the same graph.

The first appearance of change-point problem is due to Page (1954, 1955, 1957) in a detailed statistical mathematical form with consideration of cumulative sums (CUSUMS) methodology. Later, a series of researches has appeared about the change-point by various authors in the statistics domain. For instance, Sen and Srivastava (1975a)

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suggested various tests for the change-point identification in a mean level assuming a normal PDF model by the maximum likelihood estimation method, but the problem became intractable analytically, and therefore, Monte-Carlo simulation approach is used as a tedious approach. Interferences about possible change-point identification through the Bayesian approach is presented by Smith (1975) and Adams and MacKay (2007). In the same year, McGilchrist and Woodyer (1975) considered a distribution-free CUSUMS and similarly Sen and Srivastave (1975b) also suggested distribution free techniques. In these works the priory assumption was a known PDF, but Pettitt (1979) provided a methodology by releasing this assumption. He assumed a change-point existence within a given time series and then two sub-sets of the time series prior and posterior to the change-point are considered with their probability distribution functions (PDFs). He concluded that, if two PDFs are different from each other than a change-point exists. In his approach, the null hypothesis was "no-change" against the "change" alternative hypothesis. In the procedure, he used a version of Mann-Whithey statistics for the problem and derived approximately significant probabilities for testing "no-change" against "change".

In all the aforementioned works there is no indication about change-point usage for monotonic or partial trend identifications. The main concern in all the above literature works can be summarized in three points as 1) the cumulative sums, 2) mean level change, and 3) consideration of the main time series in two or more complementary sub-series that may not have equal lengths.

The significant highligths of the SAM methodology include that it is a new partial trend methodology without any assumption with the change-point concept; it identifies peak and trought change points, hence, partial trend components; and provides initial and ending points of partial trend durations and slopes.

The main purpose of this paper is to suggest and demonstrate a new change-point methodology by taking into consideration three subsequent point indication for a peak or through without any assumption. This new methodology depends on the successive arithmetic average method (SAM), which is straight forward in applications without any difficulty. The application of the methodology is presented for seven long-term (70-year) annual total rainfall data from seven different geographic and climatologic regions of Turkey.

2. Change-point methodology

The idea behind the change-point is a set of three successive points scan from the beginning of a given hydro-meteorological record until the end. If the middle point is either above or below the neighbouring points, then it is a change-point, which is known also as the turning-point or break-point in the literature. A set of measurement data where every observation is greater than the next would have no turning point whatsoever. Although there are turning-point tests in the statistical literature (Kendall and Staurt, 1988) those who work with the hydro-meteorological time series analysis did not care for them because of the availability of some common, classical and practically well-known techniques for use.

The problem is to search for the change-points in a hydro-meteorological record series for trend identification not within pre-selected time intervals, but among natural change-point occurrences. In previous literature studies, most often predetermined trend periods are considered either over the whole record length or equal halves or equal periods even more than two pieces (Mann, 1945; Kendall, 1975, Sen, 1968; Şen, 2012, 2014, 2017b). For the natural change-point trend identification let the record series be $X_1, X_2, \ldots, X_n$, where n is the record length. The methodology presented in this paper can be summarized through the following steps.

1) Generate from the original hydro-meteorological time series the arithmetic averages, $\bar{X}_i$, through the successive averages method (SAM) according to the following formulation,

$$\bar{X}_i = \sum_{i=1}^{n} \left(\frac{1}{i} \sum_{j=1}^{i} X_j \right) \tag{1}$$

2) Search for the change-points in the SAM time series sequence for local peaks and throughs. The following statements are for local peak change-point,

$$\begin{cases} If\ \bar{X}_{i-1} < \bar{X}_i > \bar{X}_{i+1} & then fix\,(i_P, \bar{X}_i) \\ Otherwise & \bar{X}_i \end{cases} \tag{2}$$

This statement provides local peak change-point location in the original time series at $(i_P, \bar{X}_i)$ position,

3) Repeat the similar procedure this time for the local through points inside the SAM series throughout the original time series as,

$$\begin{cases} If\ \bar{X}_{i-1} > \bar{X}_i < \bar{X}_{i+1} & then fix\,(i_T, \bar{X}_i) \\ Otherwise & \bar{X}_i \end{cases} \tag{3}$$

which locates in the original time series a local trough change-point at $(i_T, \bar{X}_i)$ position,

4) After the execution of the two last steps, change-point locations are clearly identified along time axis. It is worth to notice that peak and through change-points follow each other alternatively,
5) Show the change-points on the original time series graph, so that visually one can appreciate the positions of the change-points within the original record and one can make visual (linguistic) interpretations, if necessary. For instance, the time durations between two peak (through) change-points are not equal and each duration implies a partial trend within itself,
6) The connection of successive two change-points by straight-line yields to succession of partial duration trends. If the initial and final points of a trend have two successive averages ($\bar{X}_i$ and $\bar{X}_j$) corresponding to two different years (Y_i and Y_j) then the slope, S_{ij} of this trend is calculated by the following expression.

$$S_{ij} = \frac{\bar{X}_j - \bar{X}_i}{Y_j - Y_i} \tag{4}$$

7) Again visually one can compare successive pair of the local trends and the ones that are very close to each other on slope values can be considered together as a single trend.

All these steps are applied quantitatively in the following sections to actual annual rainfall records.

3. Study area and data

Fig. 1 indicates seven geographical and climate regions of Turkey each with different air movements during summer and winter seasons. The most precipitation receiving region is along the Black Sea coast.

The Black Sea region is one of the dynamic environments subject to seasonal variations, because of regional atmospheric features. It lies along the whole northern part of Turkey, which is under the effect of North Atlantic Oscillation (NAO) and Siberian air masses and they are frequently effective as frontal rainfall occurrences especially in the northeastern part of the region. Parallel to the sea coast are the high

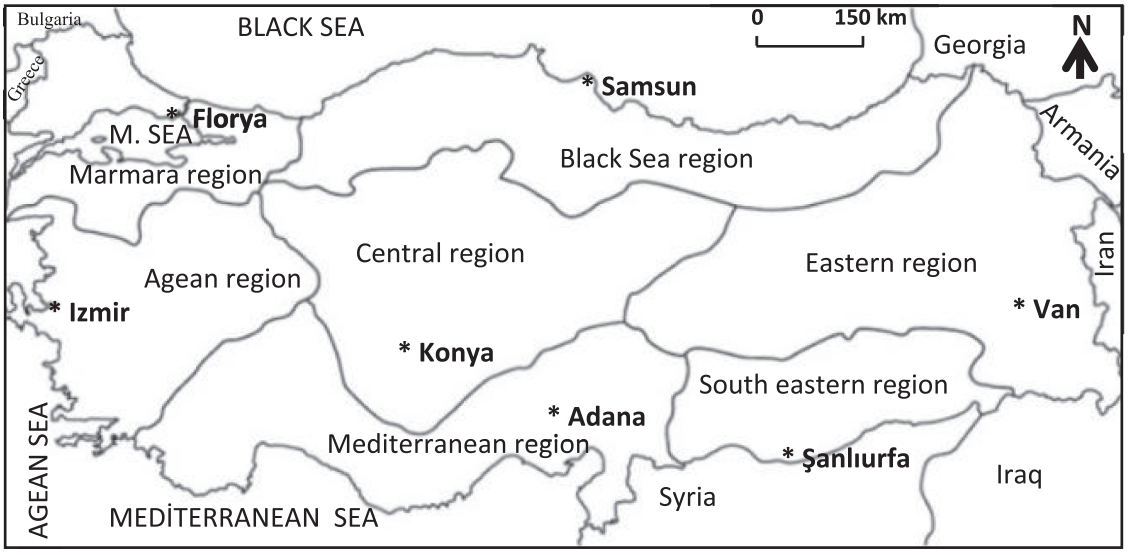


Fig. 1. Meteorology station locations in Turkey.

Table 1
Meteorology station record statistical quantities.

Station	Coordinates	Statistical parameters			
		Mean	Median	St. Dev.	Skewness
Florya, İstanbul	40° 59′ N – 28° 48′ E	645.87	626.10	113.98	0.65
İzmir	38° 24′ N – 27° 05′ E	694.32	658.95	179.06	0.38
Şanlıurfa	37° 08′ N – 38° 46′ E	324.39	323.05	75.88	0.40
Konya	37° 52′ N – 32° 29′ E	459.28	450.35	130.19	0.89
Van	38° 28′ N – 43° 21′ E	385.49	378.95	69.58	0.23
Adana	36° 59′ N – 35° 21′ E	650.82	644.05	179.93	0.90
Samsun	41° 17′ N – 36° 18′ E	691.75	691.75	116.81	0.45

mountains, which cause to local orographic rainfall occurrences. In addition to frontal ones, according to the Black Sea Climate Index, constructed using more than 100-year-long time series of the North Atlantic Oscillation, the sea surface temperature, air temperature and sea level anomaly provide a composite representation of the dominant regional climate variability mode, and explains 46% of the total variance (Oğuz et al., 2006). The representative meteorology station is at Samsun city along the coastal area.

The Marmara region has the European and Asian sides separated by the Bosporus straight in Istanbul than connects the Black Sea to the Marmara Sea and then onwards towards the south to the Aegean Sea and Mediterranean Sea. It has a temperate climate as a mergence area of the Black Sea and Mediterranean Sea climatic features. The moderate wind climate of the Marmara region is strongly influenced by land topography. The region is composed of low-lying topography surrounding the Turkish Straits System (Bosporus and Dardanelles) as a passage way for cold wind systems from the north, and for cyclones moving from the Aegean into the Black Sea (Brody and Nestor, 1980). This region has transitional climate types as humid sub-climatic, temperate and warm continental and Mediterranean climate effects. The oldest meteorology station in Turkey, namely, Istanbul Florya is located on the European side for the application in this paper.

In the Aegean Sea region, the topography has mountains perpendicular to the Sea shores, and this provides easy penetration of westerly moist air movement long distances into the land. Warm Mediterranean climate prevails in this region with modifications towards the north close to the Marmara region. Izmir city along the Aegean Sea coastal area is selected as the representative meteorology station for this study.

The Mediterranean region has Taurus Mountains parallel to the coastal areas and they leave the moisture laden southerly air movements along the coastal area and hinder penetrations to the central Turkey. Summer seasons are hot and winters have moderate cool weather occurrences.

The Central region is in the form of a closed basin, where most of the time the rainfall occurrences are of convective type during summer seasons, but in winters frontal air movements provide rainfall and snow under the continental climate regime. This region is represented by Konya meteorology station monthly rainfall amounts.

The southeastern province of Turkey is represented by the annual rainfall records at Şanlıurfa city along the Syrian border. This region has very hot summer months, whereas during the winter season temperate continental climatic effects prevail.

Finally, in the Eastern region, winter seasons are very cold with few monthly summer seasons of temperate and warm continental climate features. This region has the highest mountains in Turkey with heavy snow falls in late fall, winter and early spring months. In this area the most populated city meteorology station monthly rainfall amounts are considered for application, and this is the Van city meteorology station.

In Fig. 1 the location of each meteorology station is shown with and annual rainfall records availability from 1939 to 2010, inclusively. For the quantitative applications the location and statistical characteristics of the seven meteorology stations are given in Table 1.

It is obvious from this table that the most annual mean rainfall events take place along the coastal areas starting from the Black Sea (Samsun), Aegean Sea (Izmir), Mediterranean Sea (Adana) and Marmara Sea (Istanbul). The least rainfall amounts are in the Southeastern provinces (Şanlıurfa and Van); whereas in the central Anatolian region the annual mean rainfall amounts are in the moderate range. According to the standard deviation values, the most rainfall variability regions are also along the coastal areas.

4. Application and discussion

Prior to the application of the SAM the probabilistic behavior of each station rainfall records is given in Fig. 2 through the cumulative distribution function (CDF) form with exceedance probability levels at a set of return periods (2-year, 5-year, 10-year, 25-year, 50-year, 100-year, 250-year and 500-year) and corresponding to risk levels (0.50,

0.20, 0.10, 0.04, 0.02, 0.01, 0.004 and 0.002). It is obvious that they have rather different CDFs with different parameters for each climate region of Turkey.

The reflections of the return periods and risk levels are presented in Table 2 collectively. In 2-year return period, the Black Sea representative city, Samsun, generates the maximum rainfall with the least amounts at the Central Anatolia and the southwestern provinces of Turkey, which are the driest regions in the country. (See Table 3)

As for the SAM application consequent graphs to available time series together with the original meteorology record series are presented in Fig. 3, on which the change-points and trend are shown. On the left hand side, the graphs are obtained after the application of the seven steps in the Change-Point Methodology section for SAM series with change points and the right hand side graphs are for corresponding change-points and the trends of irregular durations as they appear naturally in the original records.

In these figures, two successive peak and through change-points correspond to the initial and final locations of partial trends. On the right-hand side graphs, partial trends are given on the original records based on the natural peak and through point's appearance in the left hand side SAM graphs. It is obvious that in both cases (peak and trough change-point successions) the trends are very close to each other. Sole dependence on one type of change-point sequence, say peak or trough, does not make very significant difference in the positions of the partial trends. The most difference between the two types of the change-points appears at the very beginnings of the records, especially because of the initial warm-up portion of about 10-year duration. This is due to the small sample sizes, which causes bias effects. More detailed numerical values about each meteorology station is given in Tables 4–10 in sequence of the meteorology stations as Istanbul-Florya, İzmir, Şanlıurfa, Konya, Van, Adana and Samsun. The number of peak and trough change-points in İstanbul-Florya meteorology station is 19 change-points each.

In the table, the occurrence years of the change-points, duration of each trend, data values of each change-point, trend slopes and relative error of each trend compared with the previous one is presented numerically. The average durations of peak and trough trends are 3.7 and 3.8 years, respectively. This implies that on the average one can consider by rounding the average persistence of trend duration as about 4 years. In the same table successive trend slopes are given as positive (+) and negative (−) numerical values with their relative slope errors in the last columns. In cases of slope error less than 0.10 then the two or more successive partial trends can be thought as a single trend. In the peak slope error column there are three cases indicated with bold italics

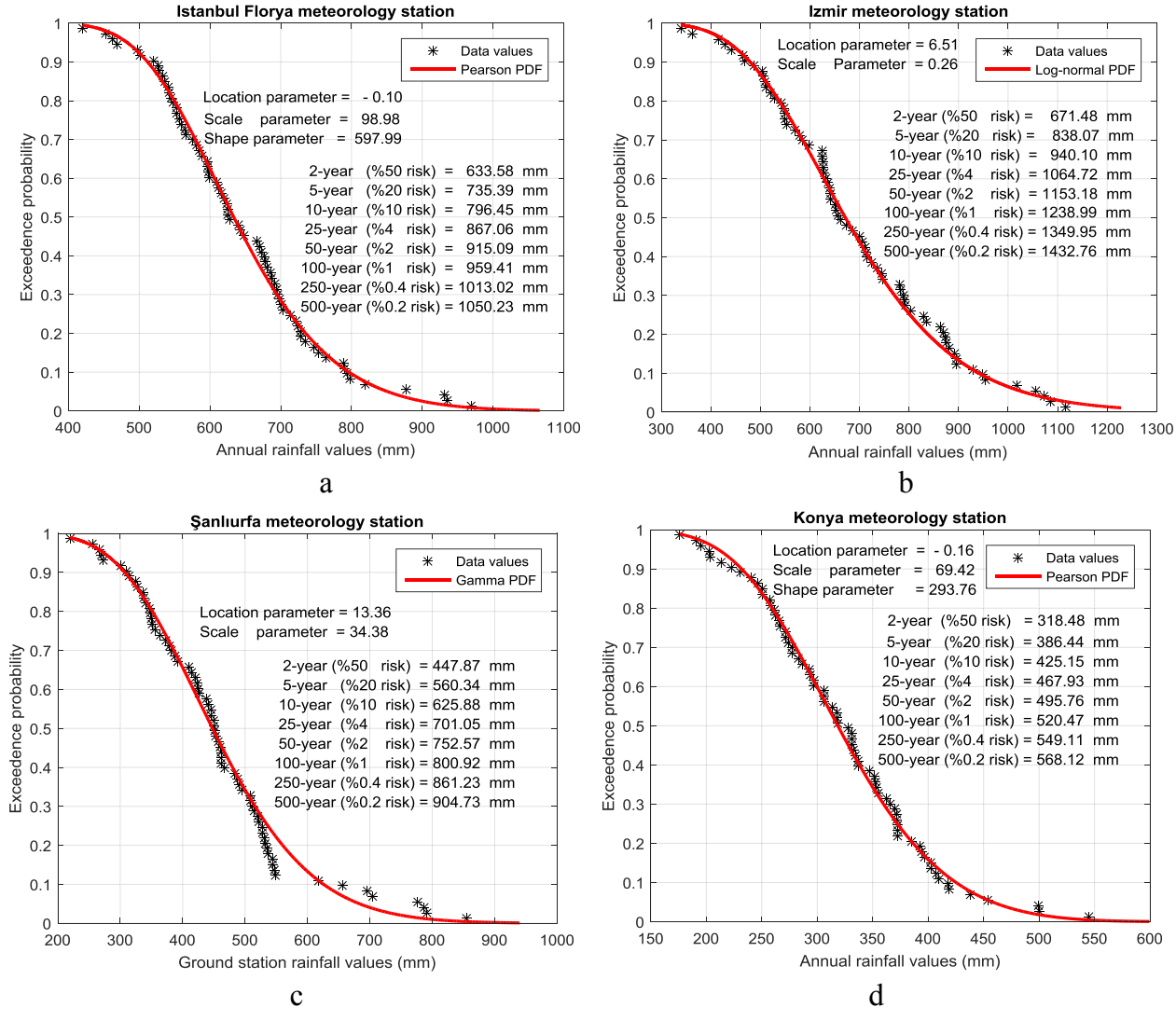

Istanbul Florya meteorology station
Data values
Pearson PDF
Location parameter = - 0.10
Scale parameter = 98.98
Shape parameter = 597.99
2-year (%50 risk) = 633.58 mm
5-year (%20 risk) = 735.39 mm
10-year (%10 risk) = 796.45 mm
25-year (%4 risk) = 867.06 mm
50-year (%2 risk) = 915.09 mm
100-year (%1 risk) = 959.41 mm
250-year (%0.4 risk) = 1013.02 mm
500-year (%0.2 risk) = 1050.23 mm
Exceedence probability
Annual rainfall values (mm)
a
Izmir meteorology station
Location parameter = 6.51
Scale Parameter = 0.26
Data values
Log-normal PDF
2-year (%50 risk) = 671.48 mm
5-year (%20 risk) = 838.07 mm
10-year (%10 risk) = 940.10 mm
25-year (%4 risk) = 1064.72 mm
50-year (%2 risk) = 1153.18 mm
100-year (%1 risk) = 1238.99 mm
250-year (%0.4 risk) = 1349.95 mm
500-year (%0.2 risk) = 1432.76 mm
Exceedence probability
Annual rainfall values (mm)
b
Şanlıurfa meteorology station
Data values
Gamma PDF
Location parameter = 13.36
Scale parameter = 34.38
2-year (%50 risk) = 447.87 mm
5-year (%20 risk) = 560.34 mm
10-year (%10 risk) = 625.88 mm
25-year (%4 risk) = 701.05 mm
50-year (%2 risk) = 752.57 mm
100-year (%1 risk) = 800.92 mm
250-year (%0.4 risk) = 861.23 mm
500-year (%0.2 risk) = 904.73 mm
Exceedence probability
Ground station rainfall values (mm)
c
Konya meteorology station
Location parameter = - 0.16
Scale parameter = 69.42
Shape parameter = 293.76
Data values
Pearson PDF
2-year (%50 risk) = 318.48 mm
5-year (%20 risk) = 386.44 mm
10-year (%10 risk) = 425.15 mm
25-year (%4 risk) = 467.93 mm
50-year (%2 risk) = 495.76 mm
100-year (%1 risk) = 520.47 mm
250-year (%0.4 risk) = 549.11 mm
500-year (%0.2 risk) = 568.12 mm
Exceedence probability
Annual rainfall values (mm)
d

Fig. 2. CDFs for each meteorology station.

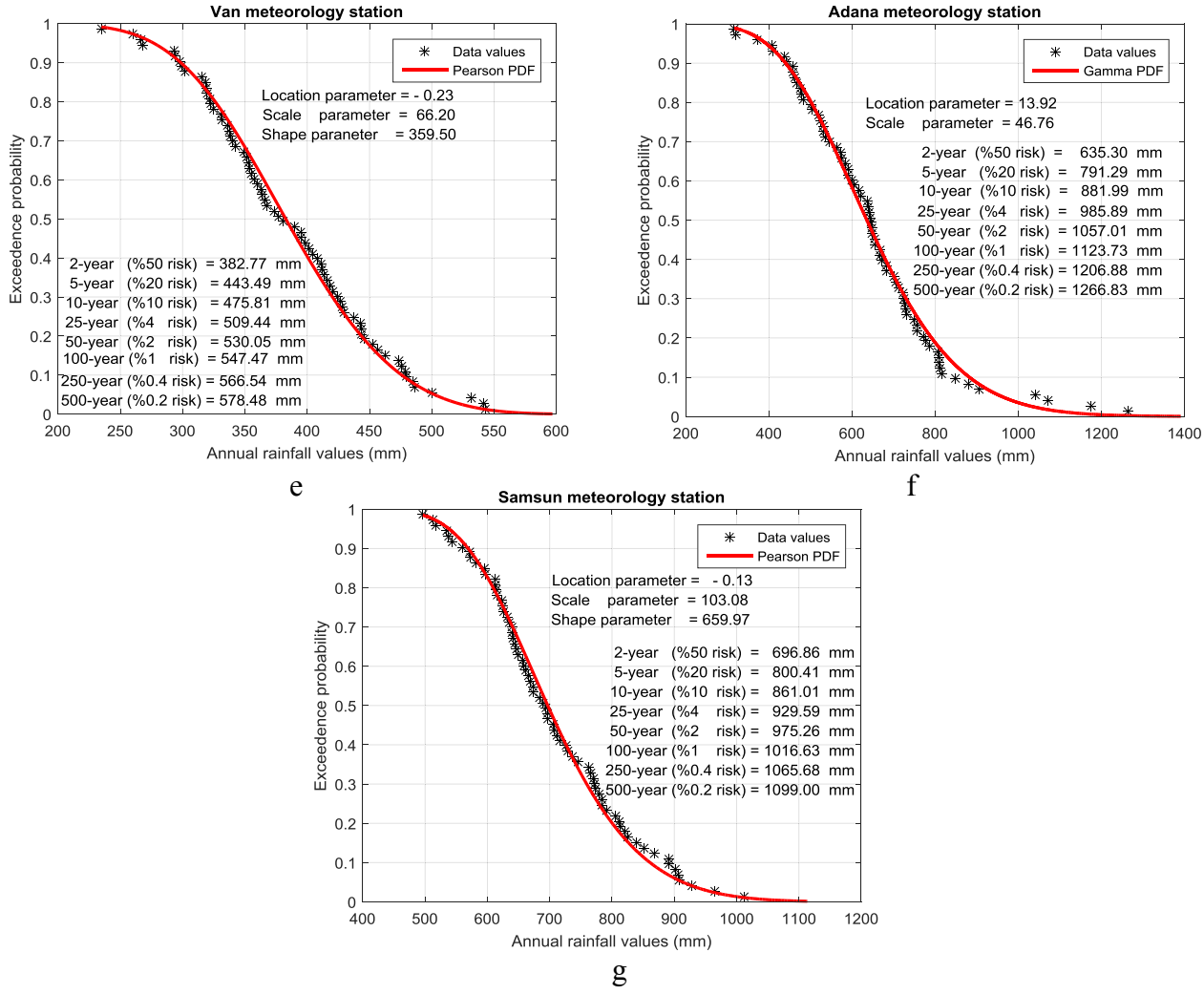

Van meteorology station
Data values
Pearson PDF
Location parameter = - 0.23
Scale parameter = 66.20
Shape paraneter = 359.50
2-year (%50 risk) = 382.77 mm
5-year (%20 risk) = 443.49 mm
10-year (%10 risk) = 475.81 mm
25-year (%4 risk) = 509.44 mm
50-year (%2 risk) = 530.05 mm
100-year (%1 risk) = 547.47 mm
250-year (%0.4 risk) = 566.54 mm
500-year (%0.2 risk) = 578.48 mm
Exceedence probability
Annual rainfall values (mm)
e
Adana meteorology station
Data values
Gamma PDF
Location parameter = 13.92
Scale parameter = 46.76
2-year (%50 risk) = 635.30 mm
5-year (%20 risk) = 791.29 mm
10-year (%10 risk) = 881.99 mm
25-year (%4 risk) = 985.89 mm
50-year (%2 risk) = 1057.01 mm
100-year (%1 risk) = 1123.73 mm
250-year (%0.4 risk) = 1206.88 mm
500-year (%0.2 risk) = 1266.83 mm
Exceedence probability
Annual rainfall values (mm)
f
Samsun meteorology station
Data values
Pearson PDF
Location parameter = - 0.13
Scale parameter = 103.08
Shape parameter = 659.97
2-year (%50 risk) = 696.86 mm
5-year (%20 risk) = 800.41 mm
10-year (%10 risk) = 861.01 mm
25-year (%4 risk) = 929.59 mm
50-year (%2 risk) = 975.26 mm
100-year (%1 risk) = 1016.63 mm
250-year (%0.4 risk) = 1065.68 mm
500-year (%0.2 risk) = 1099.00 mm
Exceedence probability
Annual rainfall values (mm)
g

Fig. 2. (*continued*)

Table 2
Meteorology station characteristics.

Station	Probability distribution function			
	Type	Parameters		
		Location	Scale	Shape
Florya, İstanbul	Pearson	− 0.10	98.98	597.99
İzmir	Log-normal	6.51	0.26	–
Şanlıurfa	Gamma	13.36	34.38	–
Konya	Pearson	− 0.16	69.42	293.76
Van	Pearson	− 0.32	66.20	359.50
Adana	Gamma	13.97	46.76	–
Samsun	Pearson	− 0.13	103.08	659.97

with less than ±10% error at 1964, 1969 and 1980. Hence, the 4-year and 2-year partial trend durations can be combined leading to 6-year partial trend duration from 1964 to 1970. Likewise, partial trends between 1976 and 1982 can be thought as a single decreasing 7-year partial trend. The reader can interpret the following tables in the same way.

In Fig. 3 İzmir meteorology station numerical partial trends are presented with all values in Table 5 similar to the previous table. At this station there are 19 peak and 18 trough change-points.

The same rules are valid also in the interpretation of this and the following tables for different meteorology stations. In this station the mean partial trend durations between two successive peak (trough) change-points is about 4.5 years, which can be considered as a round

Table 3
Meteorology station PDF description values.

Station	Return period (Risk)							
	2-year (0.50)	5-year (0.20)	10-year (0.10)	25-year (0.04)	50-year (0.02)	100-year (0.01)	250-year (0.004)	500-year (0.002)
Florya, İstanbul	633.58	735.39	796.45	867.06	915.09	959.41	1013.02	1050.23
İzmir	671.48	838.07	940.10	1068.72	1153.18	1238.99	1349.95	1432.76
Şanlıurfa	447.87	560.34	625.88	701.05	752.57	800.92	861.23	904.73
Konya	318.48	386.44	425.15	469.93	495.76	520.47	549.11	568.12
Van	382.77	443.49	475.81	509.44	530.05	547.47	566.54	578.48
Adana	635.30	791.29	881.99	958.89	1057.01	1123.73	1206.88	1266.83
Samsun	696.86	800.41	861.01	929.59	975.26	1016.63	1065.68	1099.00

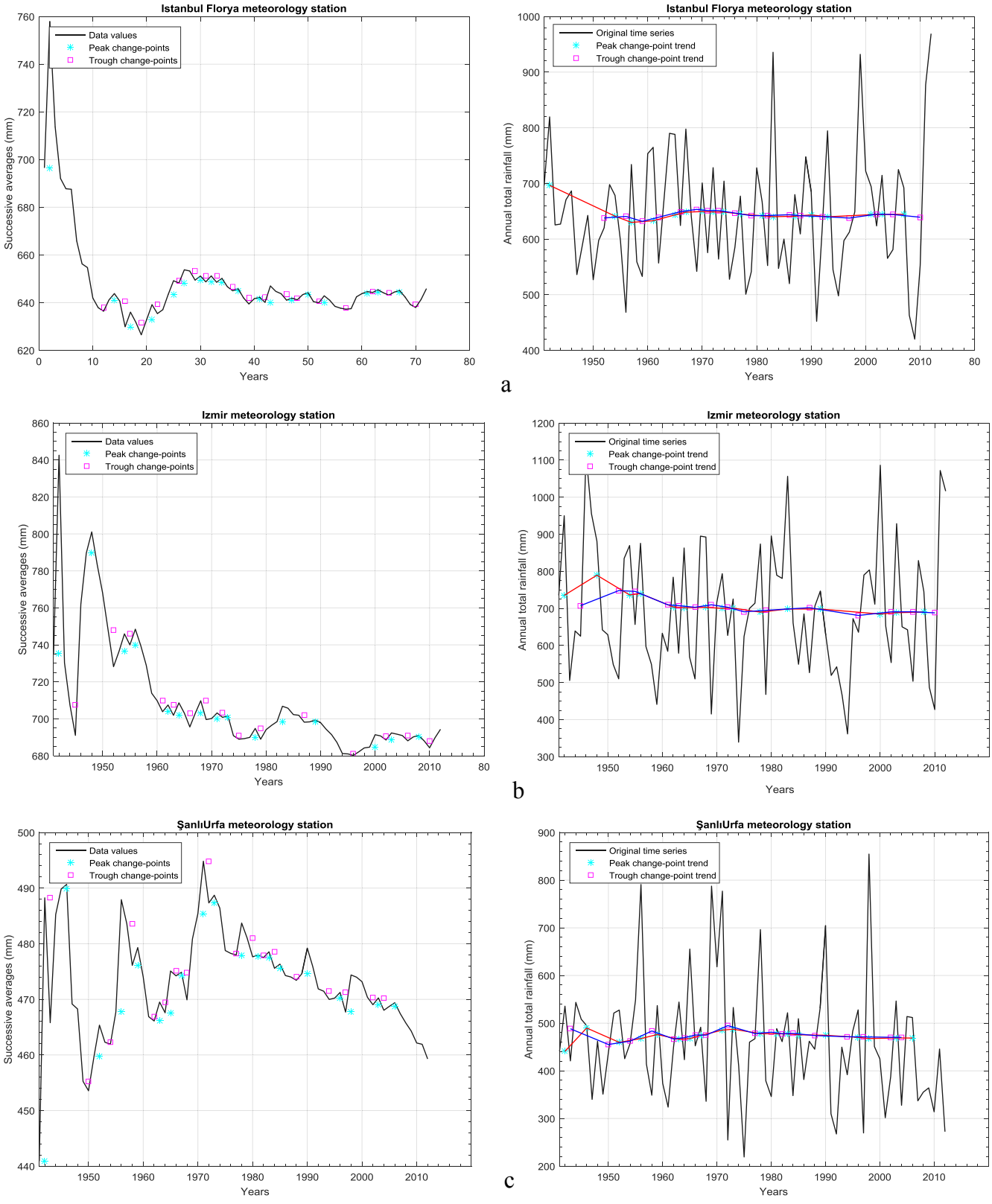
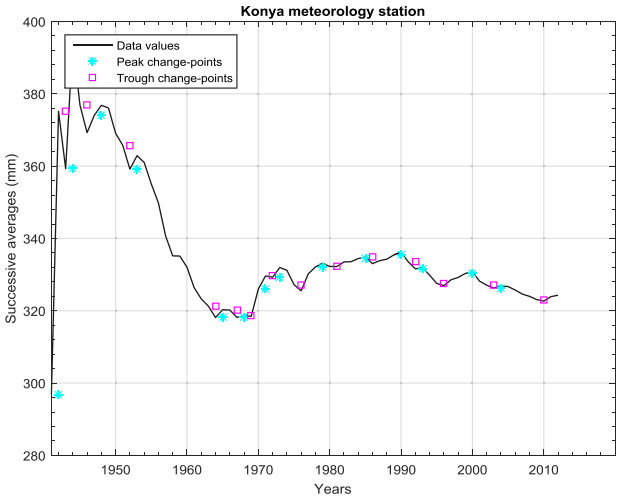
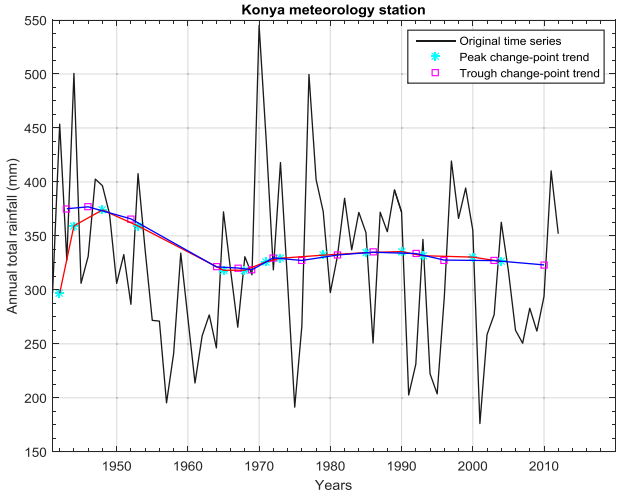


Fig. 3. SAM and trend graphs for each station.





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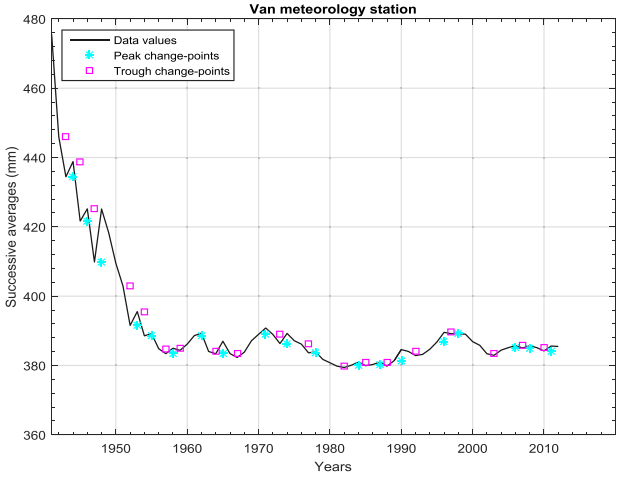

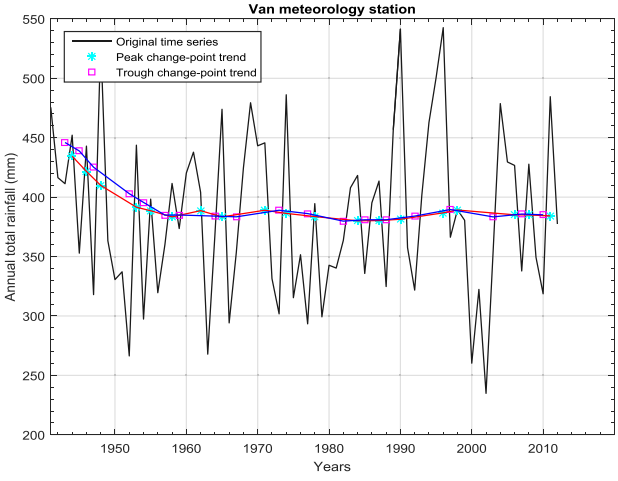

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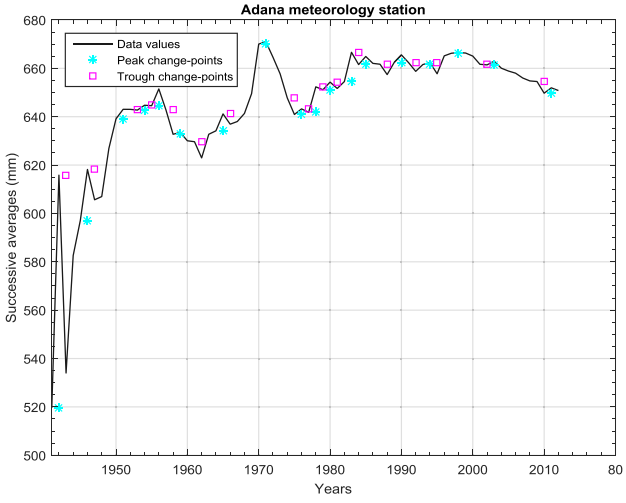

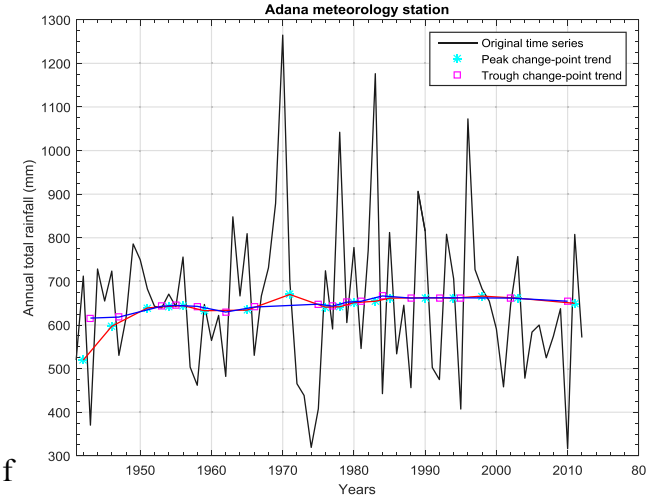

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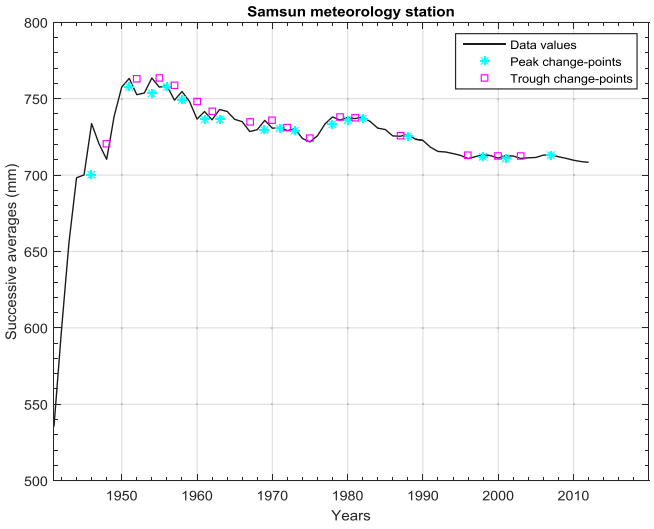
Fig. 3. (*continued*)



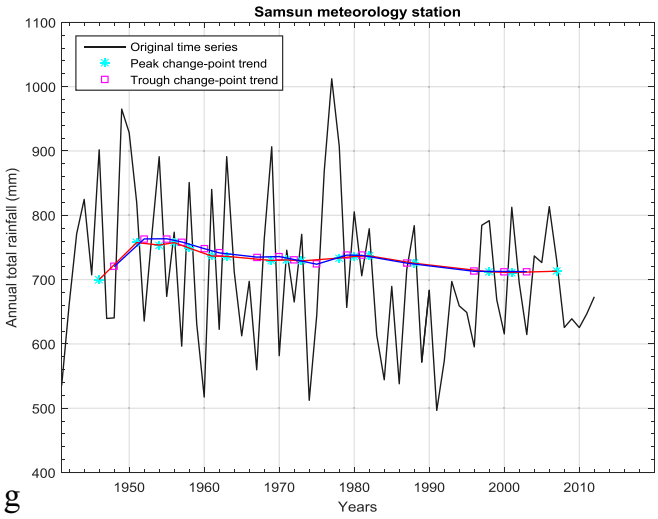


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Fig. 3. (*continued*)

value of 5 years to be on the safe side.

Table 6 is for Şanlıurfa meteorology station in the southeastern province of Turkey along the Syrian border with 19 change-points peak and trough cases. Similar peak and trough change-points are valid for Şanlıurfa meteorology station as for the İzmir station and relevant partial trend numerical values are shown in Table 6, where on the average the round trend duration is about 4 years.

Table 7 is for Konya meteorology station partial trend description values, where there appear 15 peak or valley change-point occurrences. In Konya meteorology station on the average, the partial trend durations also appear as 4 years.

Table 8 is for Eastern Turkey meteorology station (Van), which shows 17 peak and 16 valley change-points.

The partial trend durations are almost equal to each other and for practical studies, it can be recommended as 4 years.

In Table 9 Adana meteorology station trend features are given numerically.

Finally, Table 10 is for Samsun meteorology station along the Black Sea coastal area with 17 peak and 16 valley change-point possession.

Herein, the partial trend duration can be adapted from peak and valley trends as 4 years.

Table 11 indicates collectively peak and valley change-points with partial increasing and decreasing trend durations, total rainfall during each trend and trend slope for each meteorology station. This table shows that the maximum trend duration is 4.5 year for each case. According to the values in this table, except at Adana meteorology station almost all the trend slopes are negative, which may be initial signal for climate change impact indicating the rainfall decreases in recent years in Turkey.

After all what have been explained above the value the suggested methodology, its research value and superiority over the existing trend methodologies can be summarized briefly along the following points.

Table 4
İstanbul-Florya meteorology station trend features.

ISTANBUL Florya meteorology station change-points									
Peak change-points					Trough change-point				
Years	Duration (year)	Total rainfall (mm/year)	Trend slope (mm/year)	Slope error	Years	Duration (Year)	Total rainfall (mm/Year)	Trend slope (mm/year)	Slope error
1941	2	696.5	−4.6154		1951	–	637.8727	0.6918	–
1953	12	641.1154	−3.7468	−0.1882	1955	4	640.6400	−2.9744	0.767415
1956	3	629.875	0.745	−0.80116	1958	3	631.7167	2.4738	0.202361
1960	4	632.855	2.6321	2.53302	1961	3	639.1381	2.5085	***0.013833***
1964	4	643.3833	2.4179	***−0.08138***	1965	4	649.172	1.3653	0.837325
1966	2	648.2192	0.4028	−0.83341	1968	3	653.2679	−1.0656	0.28125
1969	3	649.4276	−0.3654	***−0.09285***	1970	2	651.1367	0.0223	46.78475
1971	2	648.6968	−0.0787	−0.78462	1972	2	651.1812	−1.5033	0.985166
1973	2	648.5394	−1.1928	14.15629	1975	3	646.6714	−1.5528	***0.031878***
1976	3	644.9611	−0.8315	−0.3029	1978	3	642.0132	0.0785	18.78089
1980	4	641.635	−0.7633	***−0.08202***	1981	3	642.2488	0.3664	0.785753
1982	2	640.1083	0.2286	−0.70051	1985	4	643.7145	−0.9333	0.607415
1986	4	641.0228	0.773	2.381452	1987	2	641.8479	−0.3588	1.601171
1989	3	643.3418	−1.1367	0.470505	1991	4	640.4128	−0.5449	0.341531
1992	3	639.9317	0.4786	−0.57896	1996	5	637.6884	1.3799	0.605116
2000	8	643.7608	0.2442	−0.48976	2001	4	644.5877	−0.1587	7.695022
2002	2	644.2492	0.0322	−0.86814	2004	3	644.1117	−0.9836	0.838654
Mean	**3.7**	**645.74**	**− 0.28**	**0.86**	**Mean**	**3.8**	**643.38**	**− 0.07**	**5.07**

Table 5
İzmir meteorology station trend features.

IZMIR METEOROLOGY STATION CHANGE-POINTS									
Peak change-points					Trough change-point				
Years	Duration (Year)	Total rainfall (mm)/year	Trend slope (mm/year)	Slope error	Years	Duration	Total rainfall (rm/year)	Trend Slope (mm/year)	Slope error
1941	2	735.2	9.0643		1944	5	707.5000	5.7896	
1947	6	789.5857	−8.8617	***0.022351***	1951	7	748.0273	−0.6996	0.879163
1953	6	736.4154	1.7856	−0.7985	1954	3	745.9286	−6.0239	−7.61049
1955	2	739.9867	−6.0287	2.376288	1960	6	709.7850	−1.1607	−0.80732
1961	6	703.8143	−0.9615	−0.84051	1962	2	707.4636	−1.4799	−0.27501
1963	2	701.8913	0.2725	−0.71659	1965	3	703.0240	2.242	−0.51497
1967	4	702.9815	−0.9449	2.467523	1968	3	709.7500	−2.1973	***0.019938***
1970	3	700.1467	0.3189	−0.6625	1971	3	703.1581	−4.0948	−0.86356
1972	2	700.7844	−2.1682	5.798997	1974	3	690.8735	0.9764	−0.76155
1977	5	689.9432	1.7042	−0.214	1978	4	694.7789	0.8899	***0.088591***
1982	5	698.4643	−0.0204	0.98803	1986	2	701.8978	−2.321	1.608158
1988	6	698.3417	−1.2414	−59.8529	1995	9	681.0091	1.6217	−0.30129
1999	11	684.6864	1.2825	***−0.03311***	2001	9	690.7393	0.0471	0.970956
2002	3	688.5339	0.3317	0.741365	2005	4	690.9277	−0.7196	14.27813
Mean	**4.5**	**712.1983**	**− 0.3905**	**− 3.9018**	**Mean**	**4.5**	**706.0616**	**−0.5093**	**0.51621**

Table 6
Şanlıurfa meteorology station trend features.

ŞANLIURFA meteorology station change-points									
Peak change-points					Trough change-point				
Years	Duration (year)	Total rainfall (mm/year)	Trend slope (mm/year)	Slope error	Years	Duration (year)	Total rainfall (mm/year)	Trend slope (mm/year)	Slope error
1943	4	434.4333	−6.3867		1942	3	446	−3.575	
1945	2	421.6600	−5.8871	***0.078225***	1944	2	438.85	−6.825	0.47619
1947	2	409.8857	−3.6671	0.377096	1946	2	425.2	−4.4545	0.532158
1952	5	391.5500	−1.4989	0.591257	1951	5	402.9273	−3.6829	0.209509
1954	2	388.5521	−1.7168	0.145373	1953	2	395.5615	−3.5699	0.031654
1957	3	383.4018	1.3059	0.239341	1956	3	384.8519	0.0555	63.32252
1961	4	388.6252	−1.7497	0.339842	1958	2	384.9628	−0.1827	0.696223
1964	3	383.3763	0.9352	0.465508	1963	5	384.0491	−0.207	0.117391
1970	6	388.9877	−0.8885	***0.049936***	1966	3	383.4281	0.9226	0.775634
1973	3	386.3221	−0.6682	0.247946	1972	6	388.9634	−0.7018	0.31462
1977	4	383.6495	−0.5953	***0.109099***	1976	4	386.1564	−1.2711	0.44788
1983	6	380.0774	0.0657	0.889635	1981	5	379.8007	0.3818	2.32923
1986	3	380.2746	0.3692	4.619482	1984	3	380.9461	0.0118	31.35593
1989	3	381.3822	0.9012	1.440953	1987	3	380.9815	0.768	0.984635
1995	6	386.7896	1.187	0.317133	1991	4	384.0535	1.1037	0.304159
1997	2	389.1637	−0.5046	0.574895	1996	5	389.572	−1.0315	***0.069995***
2005	8	385.1266	−0.0422	0.916369	2002	6	383.3827	0.5934	0.738288
2007	2	385.0422	−0.2825	5.694313	2006	4	385.7565	−0.2042	1.905975
Mean	**3.78**	**391.5722**	**−1.0624**	**1.0057**	**Mean**	**3.72**	**394.7469**	**− 1.2149**	**6.1536**

1) In many time series whether hydro-meteorological or industrial or any type there are surplus and deficit periods, which may have local trend components, which can be identified by the SAM methodology easily,
2) The SAM methodology provides increasing and decreasing successive trend components partially within a given time series, which provide better management works, say, in water resources systems,
3) Other trend methodologies provide a single holistic trend component for a given time series and in this manner one cannot appreciate possible internal changes that may provide risks or reliabilities concerning different time durations,
4) The SAM methodology provides on the average peak and valley change points, and hence, partial trend durations that are the most significant quantitative values for future planning and management studies,
5) The SAM methodology does require neither the normal distribution of the time series records nor serially independence as with other methodologies for trend identification in the literature,
6) The only restrictive point is the number of records, which is recommended for practical applications not less than 15 values.

Table 7
Konya meteorology station trend features.

KONYA meteorology station change-points									
Peak change-points					Valley change-point				
Years	**Duration (year)**	Total rainfall (mm/year)	Trend slope (mm/year)	Slope error	Years	Duration (year)	Total rainfall (mm/year)	Trend slope (mm/year)	Slope error
1941	2	296.8000	31.25		1942	3	375.1500	0.5833	
1943	2	359.300	3.6786	0.882285	1945	3	376.9000	−1.8561	0.685739
1947	4	374.0143	−2.9695	0.192764	1951	6	365.7636	−3.7086	0.499515
1952	5	359.1667	−3.4194	−0.15151	1963	2	321.2609	−0.3523	9.526824
1964	13	318.1333	0.0136	−0.99602	1966	3	320.2038	−0.7912	0.554727
1967	3	318.1741	2.612	191.0588	1968	2	318.6214	3.6671	0.784244
1970	3	326.0100	1.6325	0.375	1971	3	329.6226	−0.6014	5.097606
1972	2	329.2750	0.4739	0.709709	1975	4	327.2171	1.0091	0.404023
1978	6	332.1184	0.3878	0.181684	1980	5	332.2625	0.5191	0.943941
1984	6	334.4455	0.2032	0.476019	1985	5	334.8578	−0.2139	1.426835
1989	5	335.4612	−1.2864	5.330709	1991	6	333.5745	−1.5036	0.857741
1992	3	331.6019	−0.1836	−0.85728	1995	4	327.5600	−0.0692	20.72832
1999	7	330.3169	−1.0092	−4.49564	2002	7	327.0758	−0.5686	0.878298
Mean	**4.7**	**334.2167**	**− 1.0094**	**16.0589**	**Mean**	**4.0**	**337.6977**	**− 0.2989**	**3.5321**

Table 8
Van meteorology station trend features.

VAN meteorology station change-points									
Peak change-points					Trough change-point				
Years	Duration (year)	Total rainfall (mm/year)	Trend slope (mm/year)	Slope error	Years	Duration (year)	Total rainfall (mm/year)	Trend slope (mm/year)	Slope error
1943	4	434.4333	−6.3867		1942	3	446	−3.575	
1945	2	421.66	−5.8871	***0.078225***	1944	2	438.85	−6.825	0.47619
1947	2	409.8857	−3.6671	0.377096	1946	2	425.2	−4.4545	0.532158
1952	5	391.55	−1.4989	0.591257	1951	5	402.9273	−3.6829	0.209509
1954	2	388.5521	−1.7168	0.145373	1953	2	395.5615	−3.5699	0.031654
1957	3	383.4018	1.3059	0.239341	1956	3	384.8519	0.0555	63.32252
1961	4	388.6252	−1.7497	0.339842	1958	2	384.9628	−0.1827	0.696223
1964	3	383.3763	0.9352	0.465508	1963	5	384.0491	−0.207	0.117391
1970	6	388.9877	−0.8885	***0.049936***	1966	3	383.4281	0.9226	0.775634
1973	3	386.3221	−0.6682	0.247946	1972	6	388.9634	−0.7018	0.31462
1977	4	383.6495	−0.5953	***0.109099***	1976	4	386.1564	−1.2711	0.44788
1983	6	380.0774	0.0657	0.889635	1981	5	379.8007	0.3818	2.32923
1986	3	380.2746	0.3692	4.619482	1984	3	380.9461	0.0118	31.35593
1989	3	381.3822	0.9012	1.440953	1987	3	380.9815	0.768	0.984635
1995	6	386.7896	1.187	0.317133	1991	4	384.0535	1.1037	0.304159
1997	2	389.1637	−0.5046	0.574895	1996	5	389.572	−1.0315	***0.069995***
2005	8	385.1266	−0.0422	0.916369	2002	6	383.3827	0.5934	0.738288
2007	2	385.0422	−0.2825	5.694313	2006	4	385.7565	−0.2042	1.905975
Mean	**3.78**	**391.5722**	**− 1.0624**	**1.0056**	**Mean**	**3.72**	**394.7565**	**− 1.2149**	**6.1536**

5. Conclusions

An innovative methodology is presented for detection of embedded partial trend components of various durations, slopes and intercepts in a hydro-meteorological record. The basis of the approach is successive arithmetic average method (SAM), which identifies a sequence of change-points in the successive mean series of a given record, then these change-point locations are carried onto the original series with peak and through points. Finally, connection of each successive change-point types generates the partial trend components within the given series. The methodology provides the calculation of each partial trend component initial and ending points in time and average values leading to the slope calculation. The relative error between each partial trend provides useful information whether to consider the two or more as a single trend, which is recommended in cases of less than ±10%. The application is presented for seven annual rainfall records from seven different geographical and climatological regions of Turkey. In the meantime, the best probability distribution functions (PDFs) are identified for each meteorology station with quantitative values for a set of return periods and risk levels. Finally, the change-point based SAM application results are presented in graphical and table forms with meaningful interpretations. It has been calculated that both increasing and decreasing trend durations are at the maximum about 4.5 years. The sole restriction of the SAM methodology is the time series length as in any probabilistic, statistical and stochastic modeling.

The SAM approach does not depend on any pre-conditional assumptions or restrictions, and hence, can be applied for time series in any sector.

Table 9
Adana meteorology station trend features.

ADANA meteorology station change-points									
Peak change-points					Trough change-point				
Years	Duration (year)	Total rainfall (mm/year)	Trend slope (mm/year)	Slope error	Years	Duration (year)	Total rainfall (mm/year)	Trend slope (mm/year)	Slope error
1941	2	519.6000	19.375	–	1942	3	615.8000	0.5917	–
1945	3	597.1000	8.402	−0.56635	1946	4	618.1667	4.1458	0.857277
1950	5	639.1100	1.2069	−0.85636	1952	6	643.0417	0.8470	3.894687
1953	3	642.7308	0.9079	−0.24774	1954	2	644.7357	−0.6492	−0.30468
1955	2	644.5467	−3.9359	3.335169	1957	3	642.7882	−3.2828	−0.80224
1958	3	632.7389	0.2359	0.940065	1961	4	629.6571	2.8757	0.141566
1964	6	634.1542	5.9799	24.3493	1965	4	641.1600	0.7348	2.913582
1970	6	670.0333	−5.8232	***−0.0262***	1974	9	647.7735	−2.2715	−0.67651
1975	4	640.9171	0.4509	0.922568	1976	2	643.2306	4.5584	0.501689
1977	2	641.8189	4.6662	9.348636	1978	2	652.3474	0.9813	3.645266
1979	2	651.1513	1.1218	−0.75959	1980	2	654.3100	4.1129	0.761409
1982	3	654.5167	3.5212	2.138884	1983	3	666.6488	−1.2377	−2.32302
1984	2	661.5591	0.189	−0.94633	1987	4	661.6979	0.1657	6.469523
1989	5	662.5041	−0.2345	0.240741	1991	3	662.3608	0.0081	19.45679
1993	4	661.566	1.169	−3.98507	1994	3	662.3852	−0.1016	−0.92028
1997	4	666.2421	−0.9623	−0.17682	2001	7	661.6738	−0.8911	−0.88598
2002	5	661.4306	−1.4638	−0.52115	2009	8	654.5449	−0.7865	−0.13299
Mean	**3.57**	**640.10**	**2.05**	**2.07**	**Mean**	**4.00**	**647.19**	**0.58**	**2.03**

Table 10
Samsun meteorology station trend features.

SAMSUN meteorology station change-points									
Peak change-points					Trough change-points				
Years	Duration (year)	Total rainfall (mm/year)	Trend slope (mm/year)	Slope errors	Years	Duration (year)	Total rainfall (mm/year)	Trend slope (mm/year)	Slope error
1950	11	700.1000	11.498		1947	8	720.2714	10.7503	
1953	3	757.5900	−1.2941	0.88745	1951	4	763.2727	0.0805	0.992512
1955	2	753.7077	1.9162	−0.48072	1954	3	763.5143	−2.4821	29.83354
1957	2	757.5400	−4.2582	1.222211	1956	2	758.5500	−3.4518	−0.39068
1960	3	749.0235	−4.1212	***−0.03217***	1959	3	748.1947	−3.3021	***−0.04337***
1962	2	736.6600	−0.2368	−0.94254	1961	2	741.5905	−1.3227	−0.59944
1968	6	736.1864	−1.0787	−3.55532	1966	5	734.9769	0.2778	−0.78998
1970	2	729.7143	0.4812	−0.55391	1969	3	735.8103	−2.3245	7.36753
1972	2	730.6767	−0.7868	0.635079	1971	2	731.1613	−2.4057	***−0.03493***
1977	5	729.1031	0.8783	−0.11629	1974	3	723.9441	3.5337	−0.46889
1979	2	733.4946	1.2501	0.423318	1978	4	738.0789	−0.1757	0.950279
1981	2	735.9949	0.4794	0.616511	1980	2	737.7275	−2.0144	−10.4650
1987	6	736.9537	−1.9214	3.007927	1986	6	725.6413	−1.4157	−0.29721
1997	10	725.4255	−1.3329	−0.30629	1995	9	712.9000	−0.0487	−0.96560
2000	3	712.0965	−0.3361	−0.74784	1999	4	712.7051	−0.0856	−0.75770
2006	6	711.0883	0.3315	***−0.01369***	2002	3	712.4484	−0.0892	0.1345
Mean	**4.19**	**733.4597**	**0.09178**	**−0.0029**	**Mean**	**3.9375**	**− 0.27974**	**−0.2797**	**1.6220**

Table 11
Meteorology station trend features.

Station name	Meteorology station change-points					
	Peak change-points			Trough change-points		
	Duration (year)	Total rainfall (mm/year)	Trend slope (mm/year)	Duration (Year)	Total rainfall (mm/Year)	Trend slope (mm/year)
Istanbul	3.70	645.74	− 0.28	3.80	643.38	−0.07
Izmir	4.50	712.19	−0.39	4.50	706.06	−0.51
Şanlıurfa	3.78	391.57	−1.06	3.72	394.75	−1.21
Konya	4.70	334.22	−1.01	4.00	337.69	−0.29
Van	3.78	391.57	−1.06	3.72	394.76	−1.21
Adana	3.57	640.10	2.05	4.00	647.19	0.58
Samsun	4.19	733.45	0.092	3.94	− 0.28	−0.28

6. Decleration of interest statement

I disclose that I do not have any financial and personal relationships with other people or organizations that could inappropriately influence (bias) my work.

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